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# Civil and Environmental Engineering

## Faculty and Fields of Interest

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Civil and environmental engineering is the engineering of constructed facilities; of buildings, bridges, tunnels, and dams; of harbors and airports; of waterways, railways, and highways; of water power, irrigation, drainage, and water supply; of wastewater and hazardous waste disposal and environmental health systems. Civil Engineers are the professionals who plan, design, direct the construction, and often maintain these facilities.

The department offers the Bachelor of Science in Civil Engineering and the Master of Science in Civil and Environmental Engineering. The department participates in the college's co-op program.

The program is accredited by the Engineering Accreditation Commission of the Accreditation Board of Engineering and Technology, 111 Market Place, Suite 1050, Baltimore, MD 21202-4012.

**William Edberg** structural engineering

**Neil Fennessey** hydrology, water resources engineering

**Thomas Paul Jackivicz** environmental engineering, surveying

**Madhusudan Jhaveri** geotechnical engineering, solid mechanics

**Heather J Miller** geotechnical engineering

**Wala S Mogawer** transportation engineering

**Christos Papakonstantinou** structural engineering

**Sukalyan Sengupta (chairperson)** environmental engineering

### Mission

The Civil and Environmental Engineering Department at UMass Dartmouth offers a Bachelor of Science in Civil Engineering. The program provides service to meet the needs of students, industry, government, and society. The program offers excellence, access, and value through a strong commitment to teaching, scholarship, outreach, and professionalism. The program contributes to the economic development of the region by providing a resource of practice-oriented education for local industry and business, by conducting research, and by active involvement in community affairs.

### Objectives

The Department has the following program objectives:

- To educate students in the principles that underlie technological applications related to general engineering and subspecialty areas within civil and environmental engineering: structural engineering, geotechnical engineering, hydrology and water resources engineering, environmental engineering, and transportation engineering.
- To develop engineers who are articulate in communicating science and engineering concepts.
- To provide a flexible curriculum to meet the diverse needs of an ever-diverse student body, including a cooperative education program and intern opportunities.
- To empower graduates with tools related to contemporary professional practice in civil and environmental engineering at the entry level.
- To inspire graduates to become leaders in their professional endeavors.
- To inspire graduates to further their education in graduate schools, not only in engineering but also in other professions, and to encourage the attitude of lifelong learning.
- To develop an awareness in graduates of the interrelated context in which engineering is performed: political, societal, economic, and ethical.

**Civil Engineering Major**  
BS degree

**Requirements**

The academic preparation for a profession which is as varied as civil and environmental engineering requires considerable breadth as well as depth. The department provides this breadth and depth through its stated objectives. Each student's program includes a sequence of technical electives which are a combination of engineering sciences and engineering design that culminates in a meaningful major design experience. To better prepare the student to take his or her place as a citizen as well as a professional, the curriculum is also designed to include a number of courses in the humanities and social sciences.

**Calculation of the GPA in the Civil and Environmental Engineering Major**

Students must have at least a 2.000 cumulative grade point average (GPA) for all courses taken at the University in order to graduate. Students must also have at least a 2.000 cumulative GPA in the major.

For purposes of this computation all courses taken by CEN majors that are shown in the CEN catalogue requirements for the second year, third year, and fourth year (irrespective of when the courses are taken by the student), aside from the University General Education Requirements, are counted. Any additional CEN courses taken by a student beyond those required in the program description in the catalogue (extra CEN technical electives) will also be counted toward the cumulative GPA in the major but any other courses not in the catalogue requirements will not be counted.

**General Education Departmental Requirements**

Students majoring in Civil Engineering will meet their departmentally-determined General Education requirements as follows:

- Area E: CEN 452
- Area I, Tier 2: CEN 161, CEN 306, CEN 325
- Area W, Tier 2: ENL 266
- Area O: CEN 491

		Semester Credits	
		First	Second
<b>First Year</b>			
ENL 101, 102	Critical Writing and Reading I, II	3	3
CHM 151, 152	Principles of Modern Chemistry I, II	3	3
CHM 161, 162	Intro Applied Chemistry Engineers I, II	1	1
MTH 111, 112	Analytical Geometry and Calculus I, II	4	4
PHY 113	Classical Physics I		4
CEN 161	Civil Engineering Design Graphics	3	
		<b>14</b>	<b>15</b>
<b>Second Year</b>			
EGR 241, 242	Engineering Mechanics, I, II	3	3
MTH 211, 212	Calculus III, Differential Equations	4	3
CEN 201	Surveying	3	
CEN 211	Surveying Laboratory	1	
CEN 202	Mechanics of Materials <sup>1</sup>		3
CEN 212	Mechanics of Materials Lab		0.5
PHY 114	Classical Physics II	4	
MTH 331	Probability		3
ENL 266	Technical Communications	3	
	General Education Requirement	<b>18</b>	<b>15.5</b>
<b>Third Year</b>			
CEN 303	Fluid Mechanics	3	
CEN 313	Fluid Mechanics Laboratory		1
CEN 306	Structural Analysis <sup>2</sup>	3	
CEN 309	Introduction to Transportation	3	
CEN 305	Soil Mechanics	3	
CEN 315	Soil Mechanics Laboratory	1	
CEN 319	Construction Materials Lab	0.5	
EGR 232	Principles of Thermodynamics	3	
CEN 304	Introduction to Environmental Engineering		3
CEN 307	Analysis and Design of Concrete Structures		3
CEN 314	Environmental Engineering Lab		1
CEN 325	Water Resources Engineering		3
CEN 323	Geotechnical Engineering		3
CEN 334	Traffic Engineering		3
		<b>16.5</b>	<b>17</b>
<b>Fourth Year</b>			
CEN 408	Analysis and Design of Steel Structures	3	
CEN 411	Water Quality Engineering	3	
CEN 402	Engineering Economy	3	
CEN 452	Ethical, Professional, and Safety Issues	1	
	Technical Electives		6
CEN 491	Civil Engineering Project <sup>3</sup>	1	2
	General Education Requirements (C)	3	3
	General Education Requirements (D)		3
	General Education Requirements (G)		3
		<b>14</b>	<b>17</b>
		<b>Total Credits:</b>	<b>127</b>

<sup>1</sup> CEN 202 requires the completion of EGR 241 with a grade of C or better.

<sup>2</sup> CEN 306 requires the completion of CEN 202 with a grade of C or better.

<sup>3</sup> Two semester course, grades awarded in spring semester; one credit first semester; two credits second semester

## Technical Electives

All Civil Engineering majors must complete a minimum of 2 technical elective courses. They will select these courses from the technical electives list, according to a plan that is developed in consultation with the departmental advisor. In addition to the curriculum requirements, all Civil Engineering majors must take the Fundamentals of Engineering Exam by the Spring semester of their senior year.

### Technical Electives

- CEN 412 Pollution Control of Wastes
- CEN 421 Matrix Methods of Structural Analysis
- CEN 422 Design of Structural Systems
- CEN 432 Pavement Design
- CEN 433 Special Topics in Geotechnical Engineering

## Alternative Paths Program Requirements

Depending on the results of placement testing, new freshman students may be placed into one of the following first-year curricula in lieu of the standard curriculum.

		Semester Credits	
		First	Second
First Year Courses for Precalculus-Ready Freshmen			
ENL 101, 102	Critical Writing and Reading I, II	3	3
CHM 151, 152	Principles of Modern Chemistry I, II	3	3
CHM 161, 162	Intro Applied Chemistry Engineers I, II	1	1
MTH 131	Precalculus	3	
MTH 111	Analytical Geometry and Calculus I		4
CEN 161	Civil Engineering Design Graphics	3	
	General Education Elective		3
		<b>13</b>	<b>14</b>
		First	Second
First-Year Courses for Algebra-Ready Freshmen			
ENL 101, 102	Critical Writing and Reading I, II	3	3
CHM 151	Principles of Modern Chemistry I		3
CHM 161	Intro Applied Chemistry Engineers I		1
MTH 100	Basic Algebra	3*	
MTH 131	Precalculus		4
PHY 162	Science, Technology, and Society II: Environment	3	
CEN 161	Civil Engineering Design Graphics		3
	General Education Electives	6	
		<b>15</b>	<b>14</b>

\* Students receive 3 administrative credits for Math 100. Administrative credits do not count towards the total credits required for graduation.

## Civil and Environmental Engineering Courses

**CEN 161** three credits

### Civil Engineering Design Graphics

3 hours lecture, 3 hours laboratory  
The standard graphical means of communication between the civil engineer and the constructor are introduced. The students' graphic communication skills are developed including the ability to use computer-aided graphic systems.

**CEN 201** three credits

### Surveying

3 hours lecture

Prerequisite: MTH 111

A study of the theory and practice of plane surveying as applied to property, topographic, and engineering surveys, including curves, error theory and earth-work as related to civil engineering projects.

**CEN 202** three credits

### Mechanics of Materials

3 hours lecture

Prerequisite: EGR 241

The behavior of materials and members under axial load, torsion, flexure, shear and combined loads, including the deflection of beams and buckling of columns. The relationship between stress and strain, principal stresses and strains and yield and fracture criteria are discussed. Previously offered as CEN 303.

**CEN 211** one credit

### Surveying Laboratory

3 hours laboratory

Corequisite: CEN 201

Consists of field practice to understand and supplement the CEN 201 course contents.

**CEN 212** one half credit

### Mechanics of Materials Laboratory

3 hours laboratory

Corequisite: CEN 202

Laboratory experiments conducted to investigate the physical characteristics of materials and to verify the assumptions made in the course Mechanics of Materials, CEN 202. Previously offered as CEN 312.

**CEN 303** three credits

### Fluid Mechanics

3 hours lecture

Prerequisite: EGR 242

The mechanics of fluids, fluid properties, fluid statics. Kinematics and dynamics of flow fields are developed. Dimensional analysis, metering, laminar and turbulent flows will also be discussed. Emphasis is placed on energy equations with applications to closed conduit and open channel flow problems. Boundary layer concepts and

**Gen Ed note:** Civil Engineering courses satisfy the Natural Science and Technology requirement.

drag and lift forces on submerged bodies are also considered.

**CEN 304** three credits  
**Introduction to Environmental Engineering**

3 hours lecture  
Prerequisites: CEN 303, CHM 152  
Introduction to the sanitary engineering field. The environmental problems of urbanization and the natural cycle of water are discussed. Elementary hydrology, physical, chemical and biological principles of the treatment of water and wastewater are covered. Municipal services—water mains, sanitary sewers and storm water drainage, layout and operation of purification and treatment works are studied in detail. In addition, state and federal regulatory standards are introduced and discussed.

**CEN 305** three credits  
**Soil Mechanics**

3 hours lecture  
Prerequisite: CEN 202  
Corequisites: CEN 303, CEN 315  
Physical and mechanical properties of soils including weight-volume relationships, index and classification properties, compaction, permeability and consolidation characteristics. Effective stresses and soil strength parameters are also discussed. Previously offered as CEN 403.

**CEN 306** three credits  
**Structural Analysis**

3 hours lecture  
Prerequisite: CEN 202  
Analysis of forces, moments, and deformations of determinate and indeterminate beams, frames, trusses, and other structural systems. Classical and computer methods used. (Formerly offered as CEN 321.)

**CEN 307** three credits  
**Analysis and Design of Reinforced Concrete Structures**

3 hours lecture  
Prerequisite: CEN 306  
The methods of structural analysis and design of reinforced concrete beams, columns, frames, and one- and two-way slabs are formulated and discussed.

**CEN 309** three credits  
**Introduction to Transportation Engineering Systems**

3 hours lecture  
Prerequisites: CEN 201  
A comprehensive overview of the characteristics of transportation systems. Concepts in

major areas such as geometric design, human factors, traffic engineering simulation, and transportation planning and evaluation, including travel behavior and socioeconomic effects, will be introduced. Principles of highway construction and design will be included.

**CEN 313** one credit  
**Fluid Mechanics Laboratory**

3 hours laboratory  
Corequisite: CEN 303  
Laboratory experiments supplementing the theory course CEN 303 Fluid Mechanics, with the objective of introducing the student to the field of fluid observations and experimentation.

**CEN 314** one credit  
**Introduction to Environmental Engineering Laboratory**

3 hours laboratory  
Corequisite: CEN 304  
Laboratory experiments in the testing of water and wastewater. Supplements the theory course CEN 304.

**CEN 315** one credit  
**Soil Mechanics Laboratory**

3 hours laboratory  
Corequisite: CEN 305  
Laboratory experiments in testing of various types of soils. Supplements the theory course CEN 405. Previously offered as CEN 413.

**CEN 319** one-half credit  
**Construction Materials Lab**

3 hours laboratory  
Corequisite: CEN 309  
A series of laboratory experiments aimed at measuring the engineering properties of asphalt, asphalt concrete and concrete to supplement the theory covered in CEN 309. Previously offered as CEN 310.

**CEN 323** three credits  
**Geotechnical Engineering**

3 hours lecture  
Prerequisites: CEN 305, 315  
Subsurface investigation and characterization based upon current methods of laboratory and in situ testing. Bearing capacity theory and geotechnical design of shallow foundations. Introduction to analysis and design of deep foundations and earth retaining structures. Previously offered as CEN 423.

**CEN 325** three credits  
**Water Resources Engineering**

3 hours lecture  
Prerequisite: CEN 303

Elementary surface and groundwater hydrology, pressure flow and open channel flow fundamentals. Topics include basic probability and statistics with a water resources emphasis, watershed based and site drainage concepts, natural and constructed open channel systems, reservoir routing and design, analysis and management issues. Also covered are the analysis and design of pressure flow systems, dam spillways, energy dissipaters and stilling basins. An integrated, systems analyses approach to water resources engineering is emphasized. Previously offered as CEN 311.

**CEN 334** three credits  
**Traffic Engineering**

3 hours lecture  
Prerequisite: CEN 309  
Introduction to the concepts of movement control. Discussion and quantitative appraisal of the characteristics of the transport user, the vehicle, the road, the navigation and control systems. Written and oral reports are assigned on field data collections and evaluations of typical control problems, traffic studies, road user reactions, and potential future transport systems. Previously offered as CEN 434.

**CEN 400** three credits  
**Civil Engineering Internship**

Training experience for civil engineering majors at various institutions/agencies recognized by the department. Internship proposals must be approved by the department chair.

**CEN 402** three credits  
**Engineering Economy**

3 hours lecture  
Prerequisite: MTH 112  
A study of the principles involved in the analysis of proposed investment in capital assets for decision-making. Emphasis is placed on techniques for economy studies of multiple alternatives, uncertainties in forecasts, increment costs, taxes, retirement and replacement. Current economic issues, overview of economic decision-making and investment are also discussed. Enrollment is normally limited to engineering seniors.

**CEN 408** three credits  
**Analysis and Design of Steel Structures**

3 hours lecture  
Prerequisite: CEN 306  
The field of structural engineering is introduced through a study of the methods of structural analysis and design of steel structures using the Load and Resistance Factor Design Method. Previously CEN 308.

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**Note:** Some graduate courses may be open to undergraduates. Please consult your department chairperson. See the *Graduate Catalogue* for graduate general and program requirements.

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**CEN 411** three credits

**Water Quality Engineering**

3 hours lecture

Prerequisite: CEN 304

Factors influencing the physical, chemical, and biological characteristics of surface and ground waters. Unit operations and processes related to water treatment are emphasized.

**CEN 412** three credits

**Pollution Control of Wastes**

3 hours lecture

Prerequisite: CEN 411

The nature and causes of wastewater pollutants and the biological, chemical, and physical characteristics of these wastes. The analysis, treatment, and disposal of domestic, municipal, and industrial wastes are studied. Design of wastewater collection, pumping, and treatment facilities are practiced.

**CEN 421** three credits

**Matrix Methods of Structural Analysis**

3 hours lecture

Prerequisite: CEN 306

Fundamental matrix algebra including inversion of matrices. Stiffness matrices for spring assemblages, trusses, beams, and planar frames. Introduction to flexibility method. Computer programs are used by students to solve matrix equations.

**CEN 422** three credits

**Design of Structural Systems**

3 hours lecture

Prerequisite: CEN 307, 408

For students interested in a career in structural engineering, gives a basic understanding of the behavior of various two and three dimensional load carrying structural systems and also some means by which they can compare alternate structural systems. Design concepts, design assumptions, and methods of analysis are stressed. The selection of the optimum system for a particular type structure is also discussed.

**CEN 432** three credits

**Pavement Design**

3 hours lecture

Prerequisite: CEN 309

Provides a comprehensive understanding of pavement design. Basic principles and various design methods of pavements will be introduced. Major topics to be covered are stresses in flexible and rigid pavements, AASHTO design method for flexible and rigid pavements, design of overlays, design of airports, and other design methods of flexible and rigid pavements.

**CEN 433** three credits

**Special Topics in Geotechnical Engineering**

3 hours lecture

Prerequisite: CEN 305

Selected topics of special interest in geotechnical and geoenvironmental aspects of landfill design, design principals and uses of geosynthetics for drainage systems, separation, and soil reinforcement, slope stability analysis, and various other techniques for soil stabilization and site improvement.

**CEN 452** one credit

**Ethical, Professional, and Safety Issues**

2 hours lecture

Course fee, to cover cost of OSHA training. The professional nature of engineering and the code of ethics which governs its practice. Safety issues pertaining to field practice by civil engineers are covered. Students learn to make competent on-the-job decisions and improve professional practice with an emphasis on safety for workers in the field. Requirements include completing an OSHA safety certification course, for which students pay a fee.

**CEN 491** one credit in fall, two in spring

**Civil Engineering Project**

Prerequisites: Senior status

One credit in fall, two in spring. Final design experience requiring practitioner involvement, student reports, and oral presentations. An interdisciplinary, team approach is emphasized. Graded IP in fall.

**CEN 495** variable credit

**Independent Study**

Prerequisites: Upper-division standing; permission of instructor, department chairperson, and college dean. Study under the supervision of a faculty member in an area not otherwise part of the discipline's course offerings. Conditions and hours to be arranged.

**CEN 196, 296, 396, 496** three credits

**Directed Study**

Prerequisites: Permission of the instructor, department chairperson, and college dean. Study under the supervision of a faculty member in an area covered in a regular course not currently being offered. Conditions and hours to be arranged.

**Graduate Courses in Civil and Environmental Engineering**

**CEN 504** three credits

**Statistical Methods in Civil and Environmental Engineering**

Prerequisite: MTH 331 or equivalent

Concepts of the conduct of research in an empirical setting. Statistical modeling tools and techniques for handling empirical data. Dedicated software package will be used in class.

**CEN 512** three credits

**Advanced Structural Analysis**

Prerequisite: CEN 306 or equivalent

Advanced classical methods of structural analysis. Structures subjected to mechanical and thermal loads. Superposition principle. Generalized functions and their application for the analysis of structures. Influence line method. Introduction to plate and shell theory.

**CEN 514** three credits

**Environmental Water Chemistry**

Prerequisite: CEN 412 or equivalent

Chemical principles and applications of those principles to the analysis and understanding of aqueous environmental chemistry in natural waters and wastewaters. The chemistry of ionic equilibria, redox reactions, precipitation/dissolution, acid-base concepts, buffer capacity, complexation, hydrolysis and biological reactions. Applying basic principles of aqueous chemistry for quantifying complex, environmental systems. Specific examples of air-water-soil interactions and consequent effects. Heterogeneous equilibria with more than one solid phase. Kinetics and thermodynamics of some important ionic and biological reactions. Laboratory experiments.

**CEN 516** three credits

**Advanced Analysis and Design of Reinforced Concrete**

Prerequisite: CEN 307 or equivalent

Application of ultimate strength design procedures to continuous beams and frames. Analysis of biaxial bending and buckling behavior of compression members. Serviceability behavior and theories for deflection and cracking of one-dimensional and two-dimensional elements. Design of multistory structures, two way slabs, joints in buildings, and miscellaneous topics.

**CEN 517** three credits

**Prestressed Concrete Analysis and Design**

Prerequisite: CEN 307 or equivalent

Behavior, analysis and design of prestressed concrete structures. Covers flexure, shear,

axial load, torsion, bond anchorage design and construction considerations for pretensioned and post-tensioned concrete. Deflections, slab design, and study of axially loaded members.

**CEN 520** three credits  
**Advanced Steel Design**

Prerequisite: CEN 408 or equivalent  
Application of ultimate and elastic design procedures to continuous beams and frames, composite members, statically indeterminate trusses and arches. Plastic analysis and design of steel members. Fatigue and fracture of steel.

**CEN 521** three credits  
**Matrix Methods of Structural Analysis**

Prerequisite: CEN 306 or equivalent  
Fundamental matrix algebra including inversion of matrices. Stiffness matrices for spring assemblages, trusses, beams, and two and three dimensional frames. Introduction to flexibility method. Computer programs are used by students to solve matrix equations.

**CEN 522** three credits  
**Design of Structural Systems**

Prerequisite: CEN 308  
Introduction to the behavior of various two and three dimensional load carrying structural systems and also some means by which the students can compare alternate structural systems. Design concepts, design assumptions, and methods of analysis are stressed. The selection of the optimum system for a particular structure is also discussed. For students interested in a career in structural engineering.

**CEN 533** three credits  
**Special Topic in Geotechnical Engineering**

Prerequisite: CEN 305 and 315, or equivalent  
Selected topics of special interest in geotechnical and geoenvironmental engineering. Topics will include geotechnical aspects of landfill design, design principals and uses of geosynthetics for drainage systems, separation, and soil reinforcement, slope stability analysis, and various other techniques for soil stabilization and site improvement. May be repeated with change of content.

**CEN 538** three credits  
**Structural Dynamics**

Prerequisite: EGR 242 and CEN 306, or equivalent  
Behavior of structures and structural components exposed to time dependent loadings. Vibrations of systems; descriptions

of dynamic systems. Single degree of freedom and multiple degree of freedom systems. Base excitation caused by earthquake motions.

**CEN 552** three credits  
**Advanced Soil Mechanics**

Prerequisite: CEN 305 and 315, or equivalent  
Behavior of cohesionless and cohesive soils; limit analysis; failure theories and lateral earth pressures; stresses within earth mass; steady-state flow through porous media; consolidation and time rate settlement; shear strength of cohesive soils.

**CEN 554** three credits  
**Surface Water Hydrology**

Prerequisite: CEN 311 or equivalent  
Advanced analysis and methods in surface water hydrology. Linear and nonlinear hydrograph methods. Kinematic wave and other hydraulic routing techniques. Advanced techniques for evaporation, infiltration, and snow melt.

**CEN 558** three credits  
**Open Channel Flow Hydraulics**

Prerequisite: CEN 311 or equivalent  
Energy and momentum concepts, frictional resistance in open channels. Rapidly and gradually varied flow in open channels; unsteady flow in open channels; channel and culvert design.

**CEN 562** three credits  
**Water Resources Planning & Management**

Prerequisite: CEN 443 or equivalent  
Relationship of hydrology and hydraulics with the ultimate goal of designing a project. Concepts of precipitation, runoff, hydrograph analysis, frequency analysis, flood routing, hydrologic synthesis, and simulation techniques for large basins as well as urban and small watersheds. Also included are backwater curves, submerged weirs, and water hammer.

**CEN 570** three credits  
**Reaction Processes in Environmental Engineering**

Prerequisite: CEN 531 or equivalent  
Theory and application of adsorption, ion exchange, reverse osmosis, air stripping and chemical oxidation in water and wastewater treatment. Modeling engineered treatment processes.

**CEN 572** three credits  
**Advanced Processes in Environmental Engineering**

Prerequisite: CEN 531 or equivalent

Advanced concentrated study of a selected topic in environmental engineering such as non-point source pollution control, water reuse systems, new concepts in treatment technology, toxic substance control, etc. The instructor and student select topic. Courses may include specialized laboratory research, literature review, and specialty conference attendance.

**CEN 574** three credits  
**Hazardous Waste Management**

Prerequisite: CEN 514 or equivalent  
Regulations for collection, transportation, disposal and storage of hazardous wastes. Containment systems, monitoring, types of liners, new and available technologies to eliminate or recover the hazardous components of the wastes.

**CEN 580** three credits  
**GeoEnvironmental Engineering**

Prerequisite: CEN 433 or equivalent  
Principles of interaction of soil and rock with various environmental cycles. Physical and chemical properties of soil. Environmental site characterization: drilling technology, geotechnical and geophysical methods, monitoring well design and construction, groundwater, soil and gas sampling procedures, sensor technologies. Contaminant transport, detection and containment. Principles of containment facilities: landfills, leachate collection, cut-off walls, permeable barriers, stability analysis. Soil and groundwater restoration stabilization, bioremediation, washing, electrotechnologies, soil vapor technologies.

**CEN 582** three credits  
**Pavement Design**

Prerequisite: CEN 309 or equivalent  
Pavement types; pavement system components; stresses in the pavement structure. Design factors and criteria, pavement stabilization, structural design of flexible and rigid pavements for highways and airports, pavement maintenance and overlay design.

**CEN 584** three credits  
**Pavement Materials**

Prerequisite: CEN 309, CEN 319, or equivalent  
Bituminous and nonbituminous materials and mix-design, asphalt binder, bituminous mixtures, conventional and superpave mix-design methods, surface and subgrade soils, mineral aggregates, Portland cement concretes, material characterization and testing, fracture, fatigue, and permanent deformation, pavement materials and additives, and pavement recycling.

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**CEN 586** three credits

**Pavement Management**

Prerequisite: CEN 309 or equivalent  
Pavement performance concepts. Criteria for pavement evaluation. Measurement of pavement distress and structural capacity. Analysis and interpretation of pavement evaluation data. Correlation of data with performance ratings. Formulation and evaluation of maintenance and rehabilitation alternatives.

**CEN 588** three credits

**Intelligent Transportation Systems**

Prerequisite: CEN 334 or equivalent  
Application of advanced technology to the vehicle and the roadway to solve traffic congestion, safety, and air quality problems.

**CEN 590** six credits

**Masters Thesis**

Prerequisites: Graduate standing, Thesis Option, and approval of the student's Graduate Committee  
Thesis research on an experimental or theoretical project in civil and environmental engineering under a faculty advisor. A formal thesis must be submitted to fulfill the course requirements.

**CEN 592** three credits

**Masters Project**

Prerequisites: Graduate standing, Project Option, and approval of the student's Graduate Committee  
Project research in conjunction with industry or government under a faculty advisor. A formal report must be submitted to fulfill the course requirements.

**CEN 595** three credits

**Independent Study**

Prerequisites: Permission of instructor and Graduate Committee  
Study under the supervision of a faculty member in an area not otherwise part of the discipline's course offerings. Conditions and hours to be arranged.